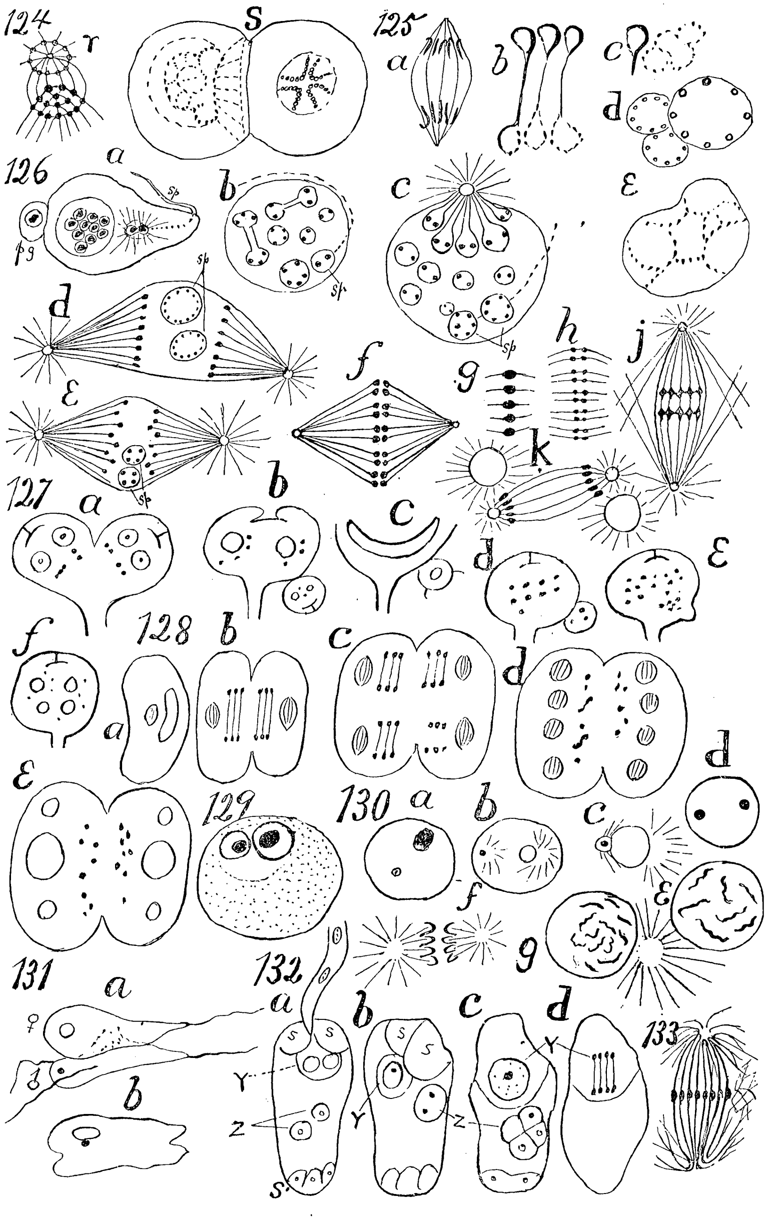
PLATE XI.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THE SIGNIFICANCE OF SEX.

BY JULIUS NELSON.

(Concluded from page 162.)

PLATE XI.

FIG. 125, *a–e*. From the segmenting egg of the *Axolotl*—Bellonci, Arch. Italiennes de Biol., vi.—Shows how the knäuel reticulum is formed from the loops. The loops in this case are hook-shaped, or almost straight rods, the end of the segment which first reaches the pole swells out and the chromatin breaks up into microsomata, the whole segment is thus transformed into a vesicle containing peripheral microsomata. These vesicles fuse as in *c*, *d*, *e*, and the microsomata become arranged in rows, which thus form a reticulating filament.

FIG. 126, *a–k*. Fertilization of ovum of *Arion empiricorum*—Platner, A. m. A., xxvii.—In *a* we see the polar globule (*pg*) and the spermatozoon (*sp*), whose head and neck have penetrated into the egg, but left the tail free. The head consists of a hyaline material holding two karyosomata. As usual astral rays surround it. The germinal vesicle contains many karyosomata, each with a hyaline envelope. The head of the spermatozoon at last becomes included in the germinal vesicle. In *b* we see the karyosomata have broken up into many microsomata arranged at the periphery of each hyaline vesicle, they fuse, so that for the most part, as in *c*, each shall contain two microsomata at opposite sides. But the hyaline vesicles themselves fuse (or divide?) as indicated by the dumb-bell forms in *b*. The hyaline mass of the male pronucleus divides, so each half has a karyosoma, and the latter passes through the same stages of segmentation and fusion as the female karyosoma, except that each vesicle has finally four microsomata instead of two (*c*, *d*, *e sp*). [Only the germinal vesicle or its contents are shown in all figures except *a*.] On the side of the germinal vesicle towards the centre of the egg there arises an aster (*c*), and some of the hyaline vesicles become club-shaped and send out stalks and put themselves into connection with it, the membrane of the germinal vesicle disappearing at this point. In *d* a second aster has arisen, also near the first, so that the two are not at first opposite each other, but become so more and more by swinging around into a right line, and as they do so the germinal vesicle sinks towards the interior of the egg; the remaining microsomata, like the first lot, now become connected with this aster, except that the male karyosomata are behindhand (*d*, *e*), but finally these also join. Meanwhile the microsomata become regularly disposed in an equatorial plate and grouped in fours, each pair of a four being united by a spindle-fibre to its own pole (*f*). Then each group of four microsomata fuse to form one karyosoma on each fibre (*g*), and again segmenting into four (*h*), they separate, leaving connecting fibrils between them. As the microsomata move polewards there is a stage, as usual, where they seem to fuse laterally (*j*). In *k* we see the spindle turned out of its position, leaving the two large polar asters *in situ*, but still possessing little ones of its own. Such is the history of the first segmentation after fertilization. By comparing it on the one side with Fig. 124, and on the other with Fig. 127, it is seen to form a connecting link.

FIG. 127, *a–f*. A case of conjugation with *Vorticella microstomum*—Engelmann, M. J., i.—When division or budding takes place the nucleus stretches into the bud and is segmented off. These buds are the microgonidia or males, and may suffer

segmentation like sperm mother-cells before being set free. The mother from which they budded is the macrogonidium, and is itself soon fertilized by a microgonidium, which is the child of another macrogonidium. *c* shows the first step in this conjugation. The nucleus, both in the macro- and the micro-individual, segments up into bits, smaller and smaller, and the microgonidium being absorbed, its microsomata are added to the more numerous microsomata of the female. Then there is gradual fusion until the single nucleus is reconstituted. Before this happens there may be division and budding, as in *a* and *b*. An exactly similar series of phenomena is described for *Epistylis plicatilis*.

FIG. 128, *a–e*. Conjugation of *Paramœcium*—Enc. Brit., "Protozoa."—This illustrates "temporary conjugation." *a* is a normal individual; *b*, two united for sexual ends. The nucleus and paranucleus divide successively, the former into many, the latter into four bits, and then they fuse again, only partially completed in *e;* but now the old nucleus becomes the new paranucleus, and the former paranucleus takes on the functions of the nucleus. The individuals separate and continue asexual division. This is probably an incomplete account of what happens. There is much controversy about this ill-understood process, but we must assume that there is mutual interchange of microsomata between the two individuals in harmony with some observations, and thus bring this process into line with what we know happens in all other cases of fertilization. (See text for further discussion.)

FIG. 129. Fertilization of egg of Bat—Van Beneden and Julin, A. B., i.—The two pronuclei are seen each in a vesicle lying in a clear space in the vitellus and in proximity to each other.

FIG. 130, *a–g*. Fertilization of ovum of *Sphærechinus brevispinosus*—Flemming, A. m. A., xx.—In *a* we see a large female pronucleus, and a smaller male pronucleus in the egg. In *b* each has been crowned by an aster. The male pronucleus now moves towards and fuses with the female pronucleus (*c*). The chromatin of the male pronucleus may split as in *d*, but soon all the chromatin of the fertilized nucleus is transformed into a segmented "skein" (*e*). At the same time polar asters appear, whose rays drive the segments to the equator (*f*), where they arrange themselves in a regular plate, split, and pass to the poles, there constituting the daughter-nuclei, one of which is shown at *g*, still crowned by its aster.

FIG. 131, *a–b*. "Genetic blending" of *Dallingeria drysdali*—J. R. M. S., April, 1886.—We may suppose the form with one flagellum, large nucleus, and granular zone to be female; then the form with three flagella and small nucleus is male. Both nuclei and bodies fuse to one individual, and then the nucleus is dissolved, and the cell is encysted, finally to burst, as myriads of spores, scarce visible under fifteen thousand diameters magnification.

FIG. 132, *a–d*. Fertilization phenomena in *Orchis latifolia*—Strasburger, Befruchtungs Vorgang bei den Phanerogamen, Jena, 1884; see also Jen. Zeits., xi.—Two sorts of nuclei, "germinative" and "vegetative," are found in the pollen-grain and tube, and these may multiply by karyokinesis. The former alone act as male pronuclei, and where there is more than one, the first one to make its way to the egg does the fertilizing; the others then are passive. The nucleus of the embryo-sac dividing sends each daughter-nucleus to its own pole, and there each undergoes division twice, producing four nuclei at each end of the sac. Then one of these from each end meet and conjugate in the centre (*z*) to form the mother-cell of the endosperm. Two of the remaining ones at the upper end (where the pollen tube enters) form the "synergids" (*s*) supposed to function in secreting a fluid attractive to the pollen-tube; the fourth becomes the ovum or female pronucleus (*y*). The three nu-

clei at the other end (s') are the antipodal cells. In *a* the male pronucleus has entered the ovum. In *b* the two have fused, but the nucleoli are still separate. In *c* the nucleoli are one; and in *d* the first segmentation spindle of the embryo is formed.

FIG. 133. A segmentation spindle from the egg of *Aulostomum gulo*—Nussbaum, A. m. A., xxvi.—To show the direct continuity of spindle-fibres with the yelk reticülum.

(*d*) FERTILIZATION.

FERTILIZATION, fecundation, copulation, conjugation, zygosis, are some of the terms used indiscriminately when referring to the fusion of sexual elements. We may refer to the *fusion* of nuclei, or of cells; or simply to the *apposition* of cells, or of individuals for sexual purposes. We shall use the term *conjugation* always in the former sense and *copulation* always in the latter. Thus we shall use the term *copulation* where other writers say "temporary conjugation." Conjugation of cells when not followed by conjugation of the nuclei produces *plasmodia;* we might use the term *zygosis* when fusion of the nuclei is involved. *Polyspermy* is where more than one male cell fuses with a female cell; and *superfecundation* implies, or should imply, the conjugation of more than two nuclei to form one *zygote.* We need one term more, and that is where, in polyspermy, the female nucleus segments by stenosis to furnish a partner for each of the male nuclei. For this case we would suggest the term *multifecundation.*

The modern theory of fertilization dates from the birth of the cell theory, when Kölliker extended its scope by advancing the view that the spermatozoon is a cell, and that it fertilizes the egg by a fusion with its substance, as against the theory that it was the fluid portion of the semen which holds the impregnating power. This view was not established until 1847, although Barry had seen the spermatozoon penetrate the ovum in 1843. It was now possible to compare fertilization with the conjugation which successive years of study continued to discover in the different groups of plants and animals, but with this line of development we are not here concerned.

In 1827, Baer described as *maturation* of the ovum the changes which the egg nucleus suffers, and Purkinje three years later named this nucleus the *germinal vesicle,* because it bursts and lets out its "generating lymph" through the germ. Attention was first called to the polar globules by Dumortier, and Müller named them *direction corpuscles* in 1848, because he thought they fixed

the plane of cleavage. It was in 1862 that Robin gave them the name they now usually bear.

In 1842, Bischoff saw the germinal vesicle expelled from the egg during maturation, and this was confirmed by other observers, and thus the idea that the polar globules were the extruded germinal vesicle was gradually established.

In 1853, Keber discovered the micropyle, and the theory o actual penetration of spermatozoa into the egg thus received more favor, speculations concerning the functions of the spermatozoon became more numerous. Bischoff held the katalytic theory, by which molecular motion was supposed imparted to the egg through the spermatozoon. Meissner thought it was a nutriment, others thought it served to help maturation, and thus for a long time the formation of polar globules was supposed to depend on fertilization. The independence of these phenomena was shown in 1875 by Hertwig.

The penetration of more than one spermatozoon was seen by several observers, and it was only gradually that the idea gained ground that normally but one spermatozoon enters the egg. Perez thought, in 1879, that there may be degrees of parthenogenesis, so that if this is strong in tendency, it does not take as many spermatozoa to saturate the ovum as if weak.

The next step was the discovery of the sexual pronuclei. The male pronucleus (so termed by Fol) was first seen by Weil in 1873, but its direct morphological connection with the head of a spermatozoon was first established by Hertwig in 1875. Hertwig also showed that the whole germinal vesicle was not extruded in the polar globules, but that the germinal dot remained to be transformed into the female pronucleus, which fused with the male pronucleus. Auerbach had seen these pronuclei fuse, but supposed they originated in opposite poles of the egg, and by uniting, the characters of the different hemispheres of the egg would be mixed. Beneden and Bütschli practically saw the same thing later, but likewise derived these bodies by endogenous formation. Fol was, however, successful in seeing the female pronucleus derived from the amphiaster which extruded the polar globule; but it remained for Hertwig, in 1877, to show that the polar bodies arise by a true karyokinetic division of the egg-nucleus, and are thus the homologues of the female pronucleus. Bütschli and Giard arrived at this result independently.

Then Whitmann was enabled to give what we consider as the true theory of the polar globules,—viz., that they represent an asexual generation of cells that once were functional.[1] Beneden, Minot, and Balfour carried this view so far as to say that the polar globules are male cells. Thus, that every cell is hermaphrodite, having male and female plasmas, and that the cells become sexed by extruding one of these plasmas. It can then no longer develop until it has fused with a cell containing plasma opposite in character to itself. The absence of polar globules in any instance does not disprove the theory, for this plasm may be gotten rid of in many different ways. But this theory has lately received its death-blow by the discovery of polar globules in parthenogenetic ova. Strasburger has modified the theory by his idea that the nucleo-hyaloplasm is primary idioplasm, while the cytohyaloplasm is secondary; the former is conservative, the latter is adaptive. Cell phenomena are due to a dynamic interaction of the two. Two nuclei may be alike, but because the cytoplasms differ the cells will develop in a different manner. Cells become sexually mature, therefore, by getting rid, by division or any other way, of certain constituents in the cytoplasm.[2] Weismann says that these constituents are histogenic plasm,—*i.e.*, plasm which belongs to the cell as a cell,—and when this is lost then the plasm, which represents the generation of tissue-cells to come from the segmenting egg, may develop. A view similar in some respects was advocated by Robin in 1875.

It is strange how many different bodies, having not the slightest homology, have been appealed to to prove the sexual nature of protoplasm. Every sort of paranucleus has been worked into line with this theory. We have already adverted to the fact that paranuclei are themselves very different bodies. Thus, in Fig. 49, Gaule's paranucleus can be homologous only with the germinal dot of the (parthenogenetic) ovum; for from it the new cell develops, while the old nucleus goes to the ground. Besides paranuclei other things have been supposed to represent the lost sexed protoplasm, such as canal-cells, perivitelline excretions,

[1] Bütschli said the polar globules are to be considered as the first stages of development due to fecundation, rather than due to maturation.

[2] The idea of Fol is that certain substances injurious to further development must be excreted. This is only a general statement of the fact that cells must accomplish a certain cycle of work before they are sexually mature, most commonly a certain number of divisions.

synergid-cells, follicle-cells, nutritive cells, seminal granules, "remains" ("Rest") of protoplasm in spore formations, and, in fact, any sort of excretion and secretion. Trouble arises in explaining cases where more than one of these modes coexist. Thus, Sabatier holds that in gametogenesis one cell buds off a number of cells, which become nutritive to the mother-cell, in the ovary; while in the testes the daughter-cells develop to spermatozoa at the expense of the mother-cell. Such a theory as this cannot possibly be universally applied, and does not explain polar globules. Our knowledge of sex has developed by two steps more. Beneden showed in ascaris that the two pronuclei are just alike, each containing two loops that are placed in order in one equatorial plate in the zygote, and split as in ordinary karyokinesis, to furnish the two daughter-nuclei. (See Fig. 124, *l–o.*) In the latter the four loops reappear as a result of the process of reconstruction, so that Beneden thought that each daughter-nucleus had still two male and two female loops; and thus every cell of the body may be considered hermaphrodite, having the chromatins of the two sexes in morphologically distinct structures; and finally, when any cell becomes sexually mature, all that happens is a cell-division at right angles to the ordinary cell-division, thus separating the male from the female chromatin. But this theory is very faulty, for in the first place the phenomena of karyokinesis have as one object the mixture of the chromatins, and we know that this is accomplished in one phase or other somewhere between two successive divisions. Then, secondly, the chromatin derived from the spermatozoon possesses the characters of its ancestry, both male and female; if this be lost the characters which fertilization has bestowed are lost; and as this loss occurs with every generation, how could there ever be an accumulation of characters?[1] Only through the idea that chromatin is sexed can such grave errors as this arise. Platner (see Fig. 126) furnished an important contribution when he showed that in Arion the number of microsomata derived from the male pronucleus is less than a fourth as great as that of the microsomata in the female pronucleus. Thus the two pronuclei bear the relation of

[1] Strasburger holds that the contributions of the ancestors in each fertilization remain distinct in different parts of the mitom. Roux, in a somewhat analogous way, thinks that each portion of the egg-plasm corresponds with a definite portion of the soma that develops from the egg.

macrogonidia and microgonidia to each other. In Limax the microsomata are approximately equal in number in the two pronuclei; and as the result, so far as fertilization is concerned, is the same in the two animals, we must believe that the pronuclei need not be morphologically equal. It has been said that the two parents furnish equal contributions of hereditary characters because the chromatin is alike in amount in the two pronuclei. But this assumes that quality depends on quantity. We cannot accept this notion. We believe the quality of the chromatin inheres in the nature of each gemmule, that the gemmules are nearly alike, and that the quantity of chromatin may readily be increased by the multiplication of the gemmules. Such multiplication may take place in the male pronucleus before fusion because of the nutritive conditions furnished by the yelk. Even if it did not increase in this way, it might happen that the reproductive vigor of the fertilizing gemmules is so great that during ontogeny they would at last outnumber the ovum gemmules. We do not know whether characters are realized in proportion to the number of the gemmules, or whether it depends on the strength of the gemmules, or, again, on some dynamic influence reciprocally acting between the gemmules. In the last supposition we might have each gemmule possessing a system of vibrations whose wave-form could be slightly altered by the proximity of differing systems; and that, finally, equilibrium being established, it would require a new fertilization to introduce a new variation. It would also be intelligible how gametes may develop parthenogenetically before fusion is accomplished where only the preliminary steps to such end have been taken. Finally, such variation could be effected by other means than by fertilization.

Under the first supposition we could understand how, if cell-division should not succeed in separating the gemmules in due proportions, we might get cells that had a preponderance of gemmules of one ancestor, and the parts of the body developed from the offspring of these cells would present the characters of one parent to the exclusion of the other. But we defer the discussion of this point to the subject of heredity.

Strasburger claims that fertilization is effected by the fusion of similar parts in two cells, cytoplasm with cytoplasm, nucleus with nucleus, and nucleolus with nucleolus. But in phanerogams it is only nuclei that migrate from the pollen-tube to fuse with

the egg, and in many animals it is only the head of the spermatozoon that makes the male pronucleus, the greater part of the flagellum not even getting into the yelk, so that we are justified in believing that fertilization is essentially a phenomenon of the mixture of chromatins. We cannot speak even of the union of "half nuclei" to make a whole nucleus, nor say that the nuclei are morphologically alike, nor yet that they are the *complements of each other* in any way. That the sexual pronuclei are physiologically alike we may infer from the fact that the characters of both parents are equally well transmitted, and from the fact that we may get both male and female parthenogenesis, which latter statement receives its best support from the evidence afforded by polyspermy and by the behavior of unfertilized eggs. We know that, aside from differences in size or in locomotor organs and other secondary characters, gametæ may differ physiologically in this way: in one, which we usually call the male, or microgamete, there has been a greater number of cell-divisions than in the female gamete, but in the latter we may, by enforced parthenogenesis, secure just as many divisions, and so make the cells alike. But neither of the gametes have divided as many times as they can, for it is possible, though more difficult than with the ovum, to get male parthenogenesis. The offspring thus resulting are more sexed, have greater desire as well as need for fusion with other cells, especially cells that have not divided as much as themselves. Unless we give such cells easy conditions of life we reach a stage when they can no longer divide. Such facts as these, observed with spores and the proto-organisms, enable us to understand certain phenomena obtaining with fertilization in higher forms of life.

We should expect that in most cases the ovum would possess a tendency to segmentation, which is realized normally under conditions of easy nutrition in parthenogenetic development, but may be realized in a less degree with other eggs. As a matter of fact there have been a number of observations in widely different groups of animals that show a sort of irregular segmentation of unfertilized eggs. I have observed such cases not infrequently. Such segmentation is slow and irregular, and probably cannot proceed as far as normal segmentation. Von Jhering saw the female pronucleus form an amphiaster in unfertilized eggs. Schneider, Greeff, Oellacher, and others have reported development in un-

fertilized eggs. But this phenomenon has not received the attention it deserves.

In polyspermy we find that not only does the female nucleus form an amphiaster, either alone or by zygosis, with one male nucleus, but that the male nuclei left unconjugated also form amphiasters. This phenomenon was first studied by Fol, 1879, but Hertwig has just published an article fully illustrating these forms. If more than one spermatozoon conjugates with the female nucleus it develops a tetraster (sometimes a triaster), or a figure having a greater number of poles according to the number of spermatozoa fusing. It results that segmentation follows a series whose terms are multiples of the normal one. But this only when there are no free spermatozoa in the yelk, for in such a case each of these also segments and receives its bud of cytoplasm, thus making the segmentation of the egg irregular. When the nuclei fuse before the spindle is formed, the number of spindles seems to depend on the number of nuclei. (This may be doubtful, as the poles seem to be determined by asters independently arising in the yelk, which migrate to the nuclei and direct their transformation.) But the amphiasters and the more complex tetrasters, etc., may also unite among themselves, regardless of sex, by superposition of poles, thus building up complex figures that may be as regular as a dodecahedron. The result is the fusion of daughter-nuclei of diverse origins. It follows, therefore, *that the spermatic nuclei after one segmentation have an affinity for each other.* Hertwig found further, that the nuclei resulting from the segmentation of pronuclei became fused again, but whether there was subsequent division and normal development remains an obscure question. The male nuclei also form triasters and tetrasters which cannot be distinguished from those made by the female pronucleus; but it is possible that in these cases multifecundation has taken place. Besides Fol and Hertwig, polyspermy has been studied by Bergh and Horst, 1881, and by Strasburger in phanerogams; Salenka and Schneider report normal development as following polyspermy; but this subject also requires further study.

Another line of study has been followed by Hertwig. It is well known that certain nuclei which are not too closely nor too distantly related to each other are prepotent in zygosis above these others, and that the egg resists the entrance of foreign

spermatozoa. By letting the eggs lie a long time in impure water Hertwig has so weakened this resistance as to effect hybridization between forms not ordinarily capable of being thus hybridized. But as he got results closely similar with unfertilized eggs and also with eggs where polyspermy of its own species took place, and furthermore, that polyspermy ensued in these cases of enforced hybridization, we must be cautious in our inferences. To leave eggs a long time unfertilized, instead of developing the tendency to fuse with any partner, ought rather to develop the opposite or parthenogenetic tendency. Strasburger thinks superfecundation arises when the gametes are not sexually mature. But here again we have no thorough knowledge of the facts. Spermatozoa have also been seen to penetrate the polar globules, which is not remarkable, as we know that these are (when the first globule has divided again) the counterparts of the female pronucleus; but Hertwig found that the spermatozoa penetrate any globule of extruded yelk (whether it has a nucleus or not) when artificially pressed out through a rift in the egg membrane. Probably, then, the attraction of the spermatozoa is for the nutriment, or for the cytoplasm, and the nuclear attraction arises later in accordance with other laws.

We see from this survey that sex in its primary sense, as inhering in the nucleus, or perhaps in Strasburger's sense as due to a peculiar stimulus of the cytoplasm upon the unsexed nucleus, sex is not an absolute condition but admits of degrees, is, in fact, a want, a hunger, which the cells may experience in different degrees. How the mixture of different characters confers vigor to cell-division we cannot explain. Perhaps we would be more general if we said that fertilization consists in broadening cell-education. Hence parasites that are cells of one idea do not need it to any extent. At present we cannot see how it is possible to explain it on physical principles. It is, however, only a confession of ignorance to refer the problem of heredity to the domain of psychology; we have explained nothing in so doing.

The Protozoa.—Here the phenomena of fertilization are very varied. In the lower flagellates more than two cells may fuse; and polyzygosis has been observed also in Actinophrys and Arcella. We must, with Lankester, also place in this category the formation of plasmodia and of the *syzygies* of Sporozoa. In these plasmodia, especially when encystment occurs, there may

be a fusion of nuclei to a greater or a less extent before spore multiplication; and the same thing happens with multinucleated forms like Gastrostyla, Actinophrys, and Actinospherium. Multinucleated cells are not separated from plasmodia by any distinct line, for in Heliozoa, Greeff found that division of the cell is facultative and optional, following the nuclear division, and if it occurs, the cell-bodies are apt to fuse again. In low forms of Protozoa conjugation also is as facultative as with those protophyta, where both male and female parthenogenesis have been noticed.

We may get conjugation between ordinary zooids, or one of the gametes may be a microgonidium while the other, not having divided so fast, remains as a macrogonidium. Again, the gametes may be due to spore formation; and here, again, the spores may be alike or unlike, and conjugation may be between like spores, or may be between macrospores and microspores. If the conditions of life are equal, the more often the cell-division has taken place the stronger is the desire and need of conjugation, so that where macrospores are parthenogenetic, microspores may be gametes. That this need of conjugation does not depend on the small quantity of idioplasm present may be gathered from two facts: first, when spore formation succeeds conjugation the resulting spores are smaller and more numerous than if parthenogenetically produced, but whereas the latter are apt to be gametes the former grow with vigor and multiply rapidly; secondly, where cell-multiplication allows time for the cell to grow as in ordinary gonidia, gametes are just as apt to form. In spore formation the microspores are not gametes more often than the macrospores because they are small, but because they have undergone division more frequently. In forms where both gonidial and sporular gametes occur, a failure to conjugate in the gonidial stage insures conjugation of the spores, while the occurrence of conjugation in the gonidial stage insures sporular parthenogenesis.

The Vorticellæ enable us to understand that fertilization has to do with quality of the gemmules and not with the number of these present. Two zooids which have resulted from the repeated division of a mother-zygote and standing near each other bend together and conjugate. But others just like these bud off a piece off the nucleus with some of the cytoplasm, and this goes swimming away until it finds the appropriate gamete (a macro-

gonidium) with which to fuse. As the chance of cross-fertilization is greater in proportion to the number of these microgonidia, they have acquired the habit of dividing a few times after their separation from the macrogonidium before starting out on their search for partners. Here, as with Arion, a small quantity only of the idioplasm is needed to effect fertilization. We do not contend that there may not be some advantage in starting with a large quantity of idioplasm, but we do call attention to the fact that, compared with the vigor due to the mixture of idioplasms of diverse experience, such advantage becomes quite secondary.

We may now pass to the consideration of the phenomena of copulation. The simplest cases join easily on to the case last considered. When the bud from the nucleus is not carried away by cell-division it may still be transferred to the interior of another cell, if such cell be brought with an aperture close to a corresponding aperture of its own cell. When the nuclear bud is produced at the time of the fertilization, Engelmann terms the gametæ "periodic hermaphrodites" (so far as this implies sex it is a misleading term). When, however, the nuclear bud remains as a permanent endoplastule and does not conjugate with the endoplast, except perhaps for a brief period in connection with fertilization, after which it is immediately budded off again to form the endoplastule, then Engelmann calls such a cell a "permanent hermaphrodite." In some cases the whole reproductive function may have passed over to the endoplastule, so that this never conjugates with the endoplast, but rather by its own division builds up the latter when this disintegrates. Periodic hermaphrodites are Stentor, Spirostoma, and Trachelius; while permanent hermaphrodites are Stylonychia, Euplotes, and Paramœcium.

Copulation is most frequent with the Ciliata, but has been observed in Peridinium and in one-chambered Rhizopods. An alternation of copulation with conjugation occurs in Stylonychia and in Platoum (Troglodytes). See Gabriel.

In connection with conjugation and copulation there is in all the higher forms a segmentation of the nucleus, or of the endoplast and endoplastule respectively. The last leads in the division, but is not divided up so finely as the endoplast. The phenomena are closely similar to those that accompany division. The cycle of segmentation and of fusion is passed through, so that the foreign idioplasm becomes incorporated into the nuclear

structure. Possibly it does not get thoroughly mixed with the nuclear idioplasm in a molecular or rather gemmular intimacy, but as this process of segmentation and fusion is repeated for each division, there is no reason to suppose that after a while this may not be attained. Thus it is that *every cell-division is a fertilization.*

In the conjugation of Stylonychia, there is a fusion of nuclei with nuclei across the body, first uniting the nuclei of the two gametes; and then the anterior nucleus (zygote) fuses with the posterior one, after which the two nuclei are reconstituted. Possibly, Engelmann says, the nucleoli (endoplastules) do likewise. In copulation of Stylonychia there is segmentation of the nuclei and probably of the nucleoli, but Engelmann was unable to observe any transfer of material between the gametes. The nuclear fragments fuse to one body and bud off the nucleoli, but here there is disagreement, for in another case it seemed as if the nuclear products were extruded (Bütschli), the nucleoli became four in number, one disappeared, two became the new nucleoli, and the fourth, dividing, formed the endoplasts.

In copulation of Anoplophrya, Schneider could not observe any exchange of nucleoli, but the nuclei sent processes into the apposed cell, which became budded off mutually and fused with the remnant of the original nucleus to form a new nucleus, while the nucleolus came from one of the four segments into which the nucleolus divided; the other three disappeared. In Paramæcium, the endoplastule and the endoplast get segmented, the former usually into four, the latter into many, granules. Then there is a fusion of the fragments, but as to how this is done, and as to whether there is any mutual interchange of idioplasm, is a question which has received a dozen different answers.

Greeff thought the nucleolus was a semen capsule and the nucleus an ovary. The "eggs" that came from the "ovary" being fertilized, developed to living embryos viviparously. Stein called that part of the nucleus which remained after budding off eggs the "placenta," Balbiani, that the eggs were laid, and Engelmann also, with many other early observers, held views of a similar nature, according to which we had here a true hermaphodite. Engelmann subsequently modified his views to some extent, but Bütschli attempted to bring the phenomena into line with his observations on tissue-cells, and so he held that the nucleus is

extruded, due to fertilization, and a new nucleus arises endogenously, and this is *rejuvenescence.* In 1882, Balbiani showed that there was an interchange of nucleoli; and Jickeli, in 1884, saw two nucleoli in the act of passing each other across the line separating the gametes. Lankester could find no interchange, but said that a portion of the segments of both bodies are lost, the remaining ones fuse to constitute the new nucleus and nucleolus, but *with reversed functions.* (See Fig. 128.)

Maupas, in 1886, said all the products of the nucleolus are lost except one; this divides, and one daughter remains and one crosses to the other gamete to fuse with the stay-at-home over there. The resulting zygotes segment to eight daughters; of these, three are absorbed, four become nuclei, and the eighth, after repeated divisions accompanying cell-division, becomes four nucleoli. The old nucleus is absorbed. Plate, in the same year, saw no interchange, but did see two nucleoli in apposition with a wall between. Gruber, however, saw the same thing, but no wall between, so that there was a chance for some interchange of substance. There was no fusion, however, for the nucleo-gametes separated and returned to divide into four. Gruber thinks the "stay-at-home" nucleolus acted in a similar way, for eight nucleoli result, and four of these fuse to form a new nucleus, the other four fuse to make a new nucleolus.

Truly, when such eminent observers disagree, who can decide? For our present purposes it is sufficient to know that there is an interchange in this case as in all others of fertilizing material, and that this is mutual and reciprocal. We cannot here, as did the older observers, speak of male and female idioplasm. That the functions of the endoplast are different from those of the endoplastule is evident, but Weismann claims that the reproductive plasma is restricted to the latter, while the former has only histogenic plasm. Thus, from a survey of fertilization in its relation to the nuclear phenomena, have we been enabled to get pretty clear notions of the significance of sex. But our morphological inquiry would not be complete did we not study the various methods of cell reproduction and observe the relations of these to the production of gametes. Several of the laws discoverable through such a survey have already been anticipated, but others will appear that are needful to the proper comprehension of the significance of sex.

Briefly, then, in conclusion, we have shown that the phenomena of life are the manifestation of forces that are organized, by being in some way connected with an ultimate unit, which unit, by multiplying and differentiating, forms units of a higher order; and these units repeat the same process, and so we get higher and higher units capable of a more complex life. Only in this way is organic life connected with inorganic life. A series of discrete degrees separates such life, as we study with the lens, from the substances with which the chemist deals. We can study the higher stadia morphologically, and only by analogy do we guess concerning the nature of the lower. We find the cell a reticulum of hyaloplasm holding microsomata in its nodes as nuclei. We find the soma of a metazoon likewise a reticulum in which the cell is the unit. As in the body, all cells come from embryonic or germinal cells, all traceable back to a single egg, so in the cell, all the differentiated gemmules, or micellæ, or tagmata[1] are descended from nuclear idioplasm, which is itself due to the multiplication of a single gemmule. Finally, we find that cell phenomena are accompanied by fusion or mixture of idioplasms that have had diverse experiences, and in some way the cell-life is thereby invigorated. Sex has been evolved as the means of effecting such fusions. The distinction of male and female has arisen comparatively late and is coupled with very secondary characters.

We have seen that half a dozen different structures are present in the cell, and that those in the spermatozoon are transformed into the different parts of its structure. Undoubtedly in the metamorphosis of all tissue-cells these structures play a part. If we could see which of these structures preponderates in a given tissue or organ, we could infer that the function of this part is similar in the cell to the function of the tissue in the soma.

Gaule's work on the cytozoan, or paranucleus, which can wander from cell to cell, and on which the cell-life depends, is yet too little known to be criticised. We may expect fuller details when Gaule has completed his researches.

[1] The ferments such as zymogen, etc., which are lower in the scale of organization than the bacteria, seem to come in somewhere near the plane occupied by the *gemmule;* but their relation to the latter is probably at present beyond the scope even of a guess.

LITERATURE BEARING ON THE SIGNIFICANCE OF THE CELL-NUCLEUS TO THE PROBLEM OF SEX.

The following are a few of the principal papers bearing on the subjects discussed in the preceding pages. The list does not include those referred to in the text, or in the explanations of the plates.

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NOTE.—The substance of what has been published under the head of Significance of Sex was originally delivered as part of a series of lectures in the spring of 1886, from random notes. In preparing the article for publication I have added historical matter and the latest literature, but the plates having been first prepared, do not contain, as they otherwise would, some of the instructive figures which accompanied this later literature.

JOHNS HOPKINS UNIVERSITY, March, 1887.

THE TACONIC QUESTION RESTATED.

BY T. STERRY HUNT.

(Continued from page 125.)

§ 15. WE have said above that Emmons, in his "Agriculture of New York," published in 1846, referred the upper portion of his Taconic to the horizon of the Calciferous Sand-rock. It is, however, important to note that in Chapter V., there devoted to the account of the "Taconic System," and previously printed separately in 1844, two years earlier, he still adhered to the